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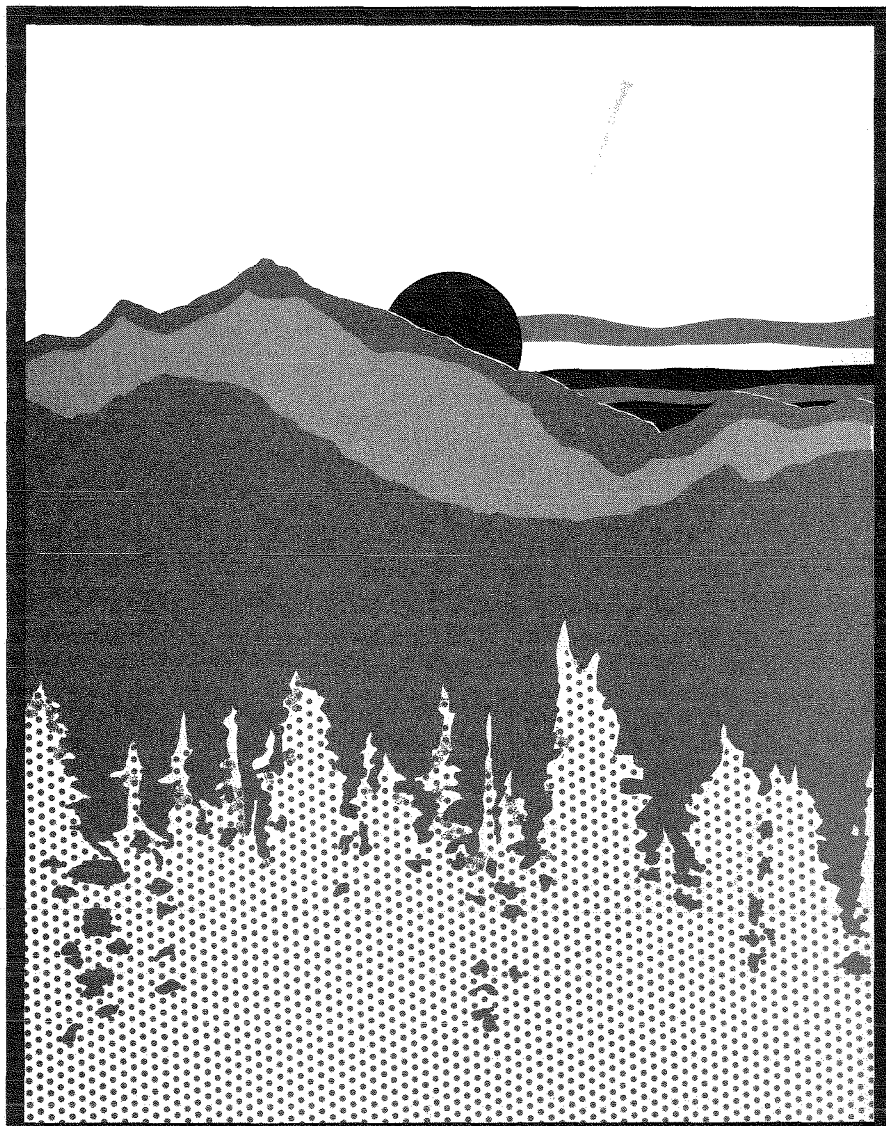

Problems of Resource Utilization

WINTER 1978

Dividing Up the Minerals of the Deep Seabed

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Since 1973, the nations of the world have been meeting in what is known as the Law of the Sea Conference, in an attempt to reach an international consensus on the use of ocean resources. While they have made considerable progress on such subjects as shipping, fishing, and waste disposal, they have failed to agree about ways of allocating the industrially important minerals of the deep seabed.

The ocean offers three forms of minerals: those dissolved in seawater, those contained in the ocean floor, and those contained in the small potato-like forms resting on top of the sedimentary ooze of the ocean floor. These latter forms, known as manganese nodules, are concretions of nickel, copper, cobalt, manganese and a number of trace minerals. Of all the ocean forms, only these nodules are now considered capable of being developed economically. Perhaps for that reason, they represent the major obstacle to a Law of the Sea Treaty—and for that reason also, they provide the focus of this paper.

A number of countries would like to control the allocation of these resources: 1) those who want to exploit these resources directly; 2) those who want to prevent, or at least delay, such exploitation; and 3) those who simply want to share directly in the benefits of exploitation. This paper explores the rationale behind each of these three basic positions. It first examines the gradually increasing profitability of ocean mining—the basic factor underlying the position of the first group of countries. It then considers the likely short-term impact of ocean mining on Third World mineral producers, should ocean mining begin under the traditional framework of free access to ocean resources. This approach permits us to examine the second group's argument that it would suffer significant losses because of ocean mining. Finally, this paper examines the probable distribution of the benefits of ocean mining, in light of the international community's growing commitment to the notion that ocean minerals (in some sense) belong to all mankind—a notion binding together the third group of nations studied here.

The first group includes chiefly the developed industrialized countries. Their basic negotiating position—particularly the U.S. position—is that private enterprise should have as free access as possible to seabed minerals. These countries, with their important groups of potential ocean miners and processors, could derive several major benefits from ocean mining: decreased import dependence, an improved balance of payments, increased government revenues (through customary taxes) and eventual trickle-down benefits to secondary producers and consumers. But in addition, the industrialized countries support their position with the economic-efficiency argument that the world output of all goods and services would be greater with unfettered ocean mining than without.

The governments of the developed countries are trying, in the interest of national security, to ensure continued supplies of strategic raw materials. They are influenced by the extreme import dependence of some of them on a number of important minerals, and by the OPEC-induced fear of future cartelization of other commodities besides oil. The industrialized countries are also motivated by the desire to assist those among their nationals who are attempting to exploit seabed minerals. The latter, generally large natural-resource companies, see the seabed as a po-

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tentially cheaper source of minerals than the increasingly costly land-based sites. These companies also have the size and experience to command the large amounts of financial capital required to develop ocean mining and processing facilities.

The countries in the second group perceive themselves as being net losers should ocean mining become important, so for their own self-interest they could be expected to try to delay ocean mining or to demand compensation for damages suffered from such activities. Those affected would include countries like Gabon and Zambia, which employ more than 10 percent of their workforce in land-based mining, or others like Zambia, Chile, and Zaire, which derive more than half their export earnings from copper. Actually, as we shall argue later, only a small number are likely to be significant net losers from a situation of untaxed ocean mining with free access to all.

The third group neither intend to mine the seabed nor support domestic mining industries which would suffer losses from such activity. At the same time, they would like to benefit from the exploitation of what they generally believe to be international property. While legal scholars still debate the issue, the seabed has become transformed from being no one's property to being everyone's property, according to this very large portion of the international community.[1] Consequently, these nations believe that all countries should share directly in the benefits generated by the seabed's use, either through taxation and regulation of private firms or through direct exploitation by an agency representing the international community.

The next three sections consider, in turn, the economic conditions or forces underlying each of the three conflicting positions. The fourth section sketches a framework for a possible compromise solution to the ocean-mining problem.

I. First Group: Profitability of Ocean Mining

In the developed world, there is keen government interest in ocean mining as a means of decreasing dependence on imported strategic materials,[2] but there is also a growing belief in the economic viability of exploiting these ocean minerals. This is suggested by the large sums of private capital already expended on exploration and research-and-development on mining and processing technology. The prospects for profitable exploitation have improved because of a rise in potential revenues, due to the rise in the prices of minerals contained in the nodules, and also because of a fall in potential production costs, especially when compared to the costs of land-based production.

Value of nodules

There has never been a market for manganese nodules, and thus no observed price either. However, a time profile of the gross value of nodules can be constructed from historical price data for the four metals most likely to be extracted from them along with prospecting data on their average mineral composition. By gross value we mean the market value of the minerals contained in a given amount of nodules, without consideration of the cost of extracting the nodules from the seabed and of extracting the minerals from the nodules. (In our calculations, we assume that the quantity of minerals mined from the ocean will be so small as to leave mineral prices unaffected.) In both nominal and price-adjusted terms, the value of nodules rose during the early and mid-1950's, peaked in about 1957, slid back until the mid-1960's, and then began an almost uninterrupted ten-year ascent to reach a new record level in 1975 (Chart 1). Over the past ten years, the value of nodules more than doubled in nominal terms and increased about 50 percent more rapidly than either the U.S. wholesale-price index or the I.M.F. index of world-traded goods.[3]

However, relative to other goods, the value of nodules until recently lagged behind their mid-1950's value. In other words, the rise in metal prices was not sufficient in itself to stimulate the recent ocean-mining rush, since producers could obtain just as attractive a real price for nodules in 1957 as they could today. The full explanation requires a consideration of the cost side of the ocean mining picture.

But first, one further point may be made about potential revenues. Nodules are almost ubiquitous in the world's oceans, yet all commercial ventures now under consideration have Pacific Ocean sites in mind. The reason is that the average Pacific nodule is roughly 20 percent more valuable than nodules from the Atlantic or Indian Oceans, since it contains a larger proportion of the more valuable minerals. Still, the variation within each ocean appears to be even greater than the variation among oceans. For example, the ocean-floor claim made by one mining consortium, Deepsea Ventures, is roughly 50-percent more valuable than the Pacific Ocean average.

Cost of ocean mining

The potential cost of nodule mining is difficult to assess, partly because commercial mining has not yet commenced, and partly because cost data is typically one of the most carefully guarded of company secrets, especially in a new industry. However, the technological environment has changed considerably since two decades ago, when the gross value of nodules first reached a peak. Details are provided elsewhere on the specific technical advances—many of them spinoffs from the offshore-oil industry—which have decreased the potential cost of ocean mining.[4]

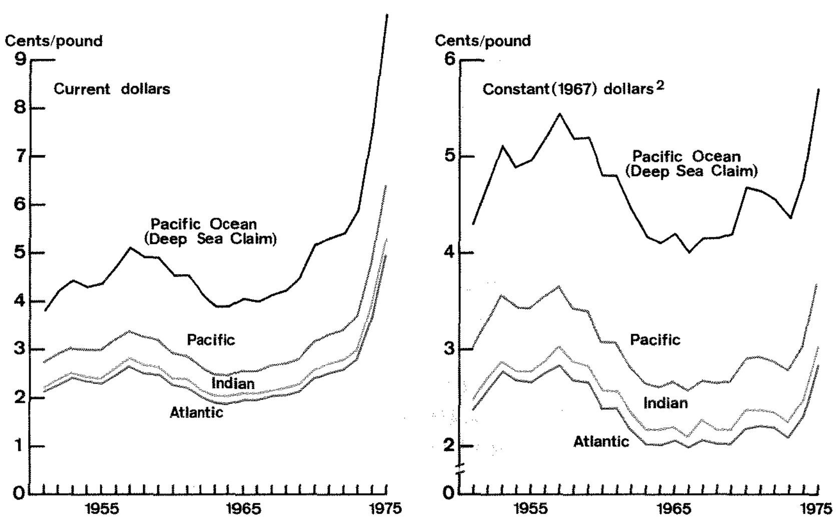
Some of these changes represent new technologies, while some represent improvements or adaptations of old technologies to new situations. Whatever the source, these changes in the technological environment have allowed all three components of ocean mining—exploration, exploitation and processing—to become relatively cheaper over the past two decades. Consequently, the ocean mining which did not take place in the mid-1950's may now do so in the early 1980's.

Ocean vs. land-based mining

But while ocean mining is now more attractive than heretofore, land-based mining may be becoming less so, which means that new mining projects may be developed on the seabed rather than on land. For a number of minerals, techno-

Chart 1

GROSS VALUE OF MANGANESE NODULES[1]



[1] Weighted sum of the annual average prices of copper, nickel, cobalt and manganese, where the weights reflect the mineral content of a typical nodule from each ocean.

[2] Deflated by the wholesale-price index.

Sources: Price data from 1) **Commodity Yearbook**, New York: Commodity Research Bureau, Inc., various years, and 2) **Yearbook of the American Bureau of Metal Statistics**, New York: American Bureau of Metal Statistics, various years. Nodule-composition data from 1) David R. Horn (ed) **Ferromanganese Deposits on the Ocean Floor**, Washington, D.C.: National Science Foundation, 1972, p. 20, p. 99, and p. 105; and Francis T. Christy Jr. (ed) **Law of the Sea: Caracas and Beyond**, Cambridge, Mass.: Bollinger, 1975.

logical improvements in land-based mining are no longer able to offset the costs of developing increasingly inferior ore bodies. Moreover, the development of increasingly remote land-based mines necessitates an increasingly expensive infrastructure—an expenditure kept to a bare minimum in ocean mining. Again, because of the inter-relationships of certain mineral prices, seabed mining may prove more attractive than one- or two-mineral land-based mining in terms of reduced revenue uncertainty.

Ore quality decline. A gradual decline in ore quality and accessibility should be expected, given the rational tendency to exploit the richest deposits first. The quality of nickel ore in New Caledonia (which produces about 18 percent of world nickel output) has declined from about 9-percent nickel in 1890 to roughly 3-percent nickel in 1950 and 2.3-percent nickel today.[5] Over the past decade, the average copper content of Kennecott's U.S. and Canadian ore has fallen from 0.82 to 0.71 percent—an ore quality decline of 13 percent.[6] Historically, technological improvements have tended to offset the effects of declining ore quality and accessibility, but this may no longer be true. According to one recent study, capital costs for a given amount of capacity rose at a 6-percent annual rate between 1965 and 1970, and 10 percent annually between 1970 and 1975—significant increases even after adjustment for inflation.[7]

In contrast to this decline in the quality of land-based ore, deep-sea nodules are virtually non-exhaustable. Nodules apparently are constantly being formed on the ocean floor, probably from dissolved minerals precipitated out of seawater around various nuclei. Scientists once believed that the formation of mineable nodules took centuries, but they no longer think so, in the light of laboratory successes as well as the recent discovery of nodules formed around soft-drink caps.

Relative infrastructure costs. Many new land mines, being located in inaccessible areas, typically require the development of shelter for workers and transport facilities for ore. For example, roughly two-thirds of $800 million invested in 11 major Australian mining projects in the 1960's went for infrastructure development.[8] In contrast, ocean mining minimizes such expenditures, since a) no railway or roads need be developed—the water can take one anywhere; b) existing port facilities can be used; and c) processing facilities can be constructed near established labor markets, eliminating the need for new worker housing.

Uncertainty. Two factors—uncertainty over cost and uncertainty over revenue—can influence choices between land-based and ocean mining. Because ocean-mining technology is new, it is clearly characterized by greater cost uncertainty than is the well-established land-based approach to mineral extraction. Yet ocean mining may be slightly less risky on the revenue side, since each ocean site typically encompasses a larger bundle of minerals than the typical land-based mine. To the extent that the prices of these joint-product minerals move against one another, revenue uncertainty would be less for the whole bundle than for only one or two minerals.

To measure that effect, we have calculated the coefficient of variation for the prices of individual metals and of nodules for the 1951–75 period. (The coefficient is a standardized variability measure which allows comparisons across commodities.) As seen in Table 1, both the six- and the four-mineral nodule extraction process would have yielded revenues at least as stable as those

Table 1
Relative Revenue Uncertainty of Nodules and Component Minerals of Nodules*

.46	Nickel	.28	Molybdenum, Vanadium
.43	Zinc		
.38	Copper**	.27	Cobalt, Manganese, Nodules (Ni, Cu, Co, Mn)
.31	Nodules (Ni, Cu, Co)	.26	Nodules (Ni, Cu, Co, Mn, Mo, V)

*As measured by the coefficient of variation of per-pound revenues of nodules and component metals, 1951–75. Coefficient of variation is the standard deviation of a variable, divided by its mean to eliminate scale effects.
**U.S. producer-price coefficient, which compares with a coefficient of .48 for London Metal Exchange price.

of any single mineral producer, and considerably more stable than those of nickel and copper producers. Even the three-mineral nodule miner would have recorded considerably more stable revenues than mines producing only nickel or copper. So if the past 25 years is any guide to the future, nodule mining should create much less revenue instability than land-based mining.

Profitability

The discussion to date only says that costs and revenues are moving in a direction which could make ocean mining eventually profitable. Is profitability a decade down the road or is it upon us today? Authorities differ widely on this point, with estimates of pre-tax rates of return to nodule mining ranging from 9 to 112 percent.[9] This should not be surprising, since such estimates require long-term forecasts of metal prices, assumptions about how many metals will be extracted from nodules, and assessments of the cost of a technology which has yet to be commercially tested.

According to one summary of these studies, the average pre-tax rate of return to nodule mining might be roughly twice the average 27-percent rate of return to U.S. mining firms (1974-75).[10] Whatever the true figure might be, the potential has already attracted at least a half-billion dollars in private sector R & D. Nonetheless, private investment in full-scale mining will probably have to wait until after the issue of property rights in the deep seabed is resolved, either by an international treaty or by unilateral U.S. action.

II. Second Group: Ocean Mining's Impact on Land-Based Producers[11]

Some countries would like to prevent the development (or slow the growth) of ocean mining in order to protect their own land-based mining industries. How significant is the threat to their interests? No conclusive answer can be made because of a lack of adequate information. Ocean mining may drive some marginal producers from the market via a world price decline for specific minerals, but one can determine which producers are the marginal ones only from information on costs of production—information which is not available. However, an indirect approach can be tried, first by examining the quantitative importance of ocean mining in four relevant metal markets, and then by examining the export-earnings vulnerability of the current mineral-producing countries.

We assume, first, that interested producers will have an unregulated, untaxed, free access to deep-sea minerals. While this situation is unlikely, it should be considered because it is the worst-case situation from the point of view of the current land-based producers. We assume, next, that 4 to 12 million metric tons of nodules will be produced annually during the first decade of ocean mining. Naturally, it is impossible to generate an econometrically-estimated supply schedule for an industry which has yet to begin operations. But according to the consensus view, four mining groups are likely to become part of the first generation of ocean miners, and each of these groups will be producing from one to three million metric tons (dry weight) of nodules per year.[12] The assumption may be somewhat unrealistic, since supply will probably not be perfectly price-inelastic even in the short run. But supply schedules for minerals tend to exhibit less than unitary price elasticity, so that the 4- to 12-million ton production assumption is probably broad enough to include any short-run adjustments in supply.

A third assumption, widely accepted in most discussion, is that most of the first-generation nodule processing will take place in the United States—and mainly on the West Coast.[13] This assumption seems safe, considering that mining will occur in the North Pacific about halfway between Hawaii and Mexico, that the U.S. already provides the largest single market for these minerals, that the U.S. (and Canada) are perceived to have the most stable investment climates in the area, and that all of the four ocean-mining groups are now based in this country.

Effect on four mineral markets

It is difficult to discuss the broader impact of ocean-mineral exploitation without first developing a sense of the relative importance of each ocean mineral in its own market. Despite the existence of a number of trace minerals in nodules (such as vanadium, molybdenum and zinc), it is generally believed that only nickel, copper, cobalt and perhaps manganese can be commercially extracted. The total value of all four metals would be roughly $15 billion, if their 1974 mine production were valued at U.S. refined prices. Copper would account for four-fifths of total value, and nickel for most of the rest. Cobalt and manganese are relatively unimportant in terms of volume, but they are both important industrial materials—manganese, for example, currently has no substitute in steel production.

The impact of ocean mining on each of these metal markets can be ascertained by examining the ratio of the potential seabed production of each mineral to its current land-based production (Table 2). The various ratios suggest that seabed copper will scarcely make a dent in the world copper market, while seabed cobalt will play a very significant role in the world cobalt market. Seabed production of the other two metals should fall somewhere between those two extremes. (Only one of the four ocean-mining groups currently plans to extract manganese, so the manganese column probably should be scaled down by a factor of four.)[14] It should be noted that the table compares hypothetical seabed production in the early 1980's with actual land-based production in 1975. Since land-based production should increase over the next several years, the ratios of sea to land production should be smaller than what the table indicates for the early 1980's.

A more refined analysis of the impact of ocean mining has been attempted by F. Gerald Adams.[15] In his study, Adams built, borrowed, modified and integrated economic models for the four metal markets, then simulated the production of from one to 20 million tons of nodules, in order to determine new equilibrium levels of prices and quantities. For example, with an intermediate output assumption (7 million metric tons), world mineral prices in the sixth year of operations would tend to be lower than they would be without ocean mining by the following amounts: copper, 1.6 percent; manganese, 2.9 percent; cobalt, 9.7 percent; and nickel, 11.6 percent. Adams' models leads to different conclusions than those suggested by our own Table 2. Specifically, he finds manganese and cobalt price reductions to be much smaller than would be indicated by Table 2 because he treats these two markets as oligopolistic. For example, he has Zaire reducing its cobalt output by almost the full new supply from the ocean, thus considerably dampening any price decline.

Trade patterns and export earnings

In theory, the creation of a new ocean-mining industry could affect three categories of internationally-traded goods: 1) the minerals to be mined from the ocean floor (since both the level and distribution of production of these minerals will be altered), 2) the factors of production to be used in the new industry (since both the level and international distribution of demand for these factors will change), and 3) the various intermediate and final products produced with these minerals (since the increased supply and lowered cost of these minerals should increase the supply

Table 2
Seabed Production of Minerals as a Proportion of 1975 Land-Based World Production*

Nodule Mining Capacity (Millions of metric tons)	Manganese	Nickel	Copper	Cobalt
1	3.0	1.8	0.1	8.9
5	14.9	8.6	0.7	44.6
10	29.9	17.2	1.5	89.2
15	44.8	25.8	2.3	133.7
20	59.6	34.4	3.1	178.4

*Average nodule mineral content from Deepsea Venture estimates, i.e., 29.00% manganese, 1.28% nickel, 1.07% copper and 0.25% cobalt. World production figures taken from *Commodity Yearbook, 1976.*

and lower the cost of the goods produced with them). In practice, any shifts in the trade patterns of the latter two categories of goods are likely to be negligible. In the one case, the demand from the ocean-mining industry for any factor of production is likely to constitute an imperceptibly small portion of the total demand for that factor. In the other case, the value of raw materials generally represents only a small portion of the value of the final (or even intermediate) product, so that declines in mineral prices should have little effect on the prices or supply of intermediate or final goods. We may thus confine ourselves to a discussion of the changes affecting the minerals themselves.

The shift in trade patterns will reflect the fact that most first-generation nodule processing will take place in the United States. Thus, the immediate effect of nodule mining will be to displace U.S. imports of nickel, copper, cobalt, and manganese.[16] Exporting countries will then attempt to sell this displaced metal in other markets. Prices will fall, but given the price-inelastic nature of mineral demand, the increase in the quantity sold will not be sufficient to prevent aggregate mineral revenues from falling. The countries hurt the worst will be those with mines that were just marginal at the old price, since these mines (if not subsidized) will be forced to close down.

Since no information is available on the relative cost structures of current land-based producers, it would be difficult to forecast which countries would suffer mine closures and layoffs, along with the consequent declines in national income and export earnings. But by constructing a worst-case scenario, we can determine which countries might face serious problems should they find themselves with a string of closed mines after the establishment of a post-ocean mining equilibrium. The analysis is confined to the potential decline in export earnings, because data constraints make it difficult to estimate the purely domestic effects of mining operations.

The initial adjustment to ocean mining involves the potential displacement of metals currently imported into the U.S. Land-based producers incur certain adjustment costs in this stage, but many of them will be able to find buyers in other markets within a relatively short time. The second, and more serious, stage is the movement to a final structure of trade, in which ocean mining has become established and marginal producers have been closed out of the market.

By comparing total imports to potential seabed production, we can roughly determine the extent to which total U.S. imports may be displaced by the advent of ocean mining. Again, by noting the share of each country's mineral production exported to the United States, we can determine how seriously that country would be affected by such displacement (Table 3).

The data suggest that seabed production could completely displace any one country's exports of any of the four minerals in the U.S. market, with the possible exception of Canadian copper and nickel. This means that high-cost producers presently exporting to the U.S. should begin searching for alternative outlets for their minerals. Second, while roughly a quarter of U.S. imports of copper and two-thirds of U.S. imports of nickel and manganese may be displaced by seabed minerals, the cobalt impact could be even more dramatic. The U.S. could actually become a net exporter of cobalt, producing more than twice as much from the sea as she currently imports. Thus, present cobalt exporters would not only be displaced in the U.S. market, but could also find themselves competing with seabed cobalt in other markets.

Some countries send very large shares of their mineral output to the U.S.—roughly a third in the case of Mexican and Japanese manganese, Zairean and Finnish cobalt, Peruvian copper and Rhodesian and South African nickel; and roughly a half in the case of Canadian and Dominican nickel. The closer their average variable costs are to the current price, the more difficulty they will have in shifting from the U.S. market to other markets, especially while new ocean supplies are creating downward pressure on mineral prices.

Many of the countries displaced from the U.S. market could compete with other producers in other markets, with the ultimate losers being countries who do not even appear on the present list of U.S. suppliers. In order to determine which countries are at risk and stand to lose the most, it is necessary to consider all metal exporters, noting the share of each country's export earnings

Table 3
U.S. Imports in 1973 of Metals to be Extracted from Seabed Nodules

Manganese

Supplier	Imports 1,000 Short Tons	Share of Production Exported to U.S.
Brazil	303	27%
Gabon	196	19
South Africa	167	9
France	107	a
Australia	61	8
Mexico	44	31
Norway	39	a
Zaire	36	20
India	35	6
Japan	21	36
Ghana	19	14
Morocco	14	17
Other	16	17
Total imports–1973	1,058	
Total imports–1981	1,411[d]	
Seabed output, low[e]	320	
Seabed output, high[e]	959	
High seabed/1981 imports	70.0%	

Cobalt

Supplier	Imports 1,000 lbs.	Share of Production Exported to U.S.
Zaire	11,196	34%
Belgium	4,819	b
Norway	972	b
Finland	909	33
Canada	666	17
France	204	b
U.K.	192	b
Taiwan	109	b
West Germany	40	b
Australia	5	0
Other	89	b
Total imports–1973	19,201	
Total imports–1981	25,601[d]	
Seabed output, low[e]	22,000	
Seabed output, high[e]	66,000	
High seabed/1981 imports	257.8%	

Copper

Supplier	Imports 1,000 Short Tons	Share of Production Exported to U.S.
Canada	142	16%
Peru	86	36
Chile	54	7
South Africa	23	12
Philippines	15	6
Mexico	11	12
Zambia	5	1
Other	36	5
Total imports–1973	372	
Total imports–1981	496[e]	
Seabed output, low[e]	47	
Seabed output, high[e]	142	
High seabed/1981 imports	28.6%	

Nickel

Supplier	Imports 1,000 Short Tons	Share of Production Exported to U.S.
Canada	121	45%
Norway	15	c
Dominican Republic	14	53
U.K.	11	c
New Caledonia	10	9
Australia	5	10
Rhodesia	4	30
USSR	4	2
South Africa	3	30
France	2	c
Greece	2	12
Other	1	12
Total imports—1973	192	
Total imports—1981	256[d]	
Seabed output, low[e]	56	
Seabed output, high[e]	169	
High seabed/1981 imports	66.0%	

[a] *France* obtains all its manganese from Gabon, Morocco and Brazil. *Norway* obtains its manganese from Brazil.
[b] *Belgium* obtains its cobalt from Zaire, *Norway* from Canada, U.K. from Zambia, *West Germany* from Finland. *Taiwan's* source is unknown. *Other* obtains cobalt from Zambia and Australia.
[c] *Norway* obtains its nickel from Canada, *U.K.* from Canada and South Africa, and *France* from its possession, New Caledonia.
[d] Import assumption: By 1981, imports will grow 3.5 percent annually, in line with the long-term real rate of growth of the U.S. economy. Ocean mining is expected to begin in 1981 at the earliest.
[e] Production assumption (with four firms): One million metric tons of nodules each at low output, and three metric tons each at high output. (Only one firm will extract manganese from nodules.) Nodule-composition assumption (Deepsea Venture average): 29.0 percent for manganese, 1.28 percent for nickel, 1.07 percent for copper, and 0.25 percent for cobalt.
Source: *Mineral Facts and Problems, 1975.*

derived from these metals and the level of each country's exports compared to potential seabed output. Two categories should be differentiated: 1) copper exporters, whose price will be largely unaffected by the arrival of seabed copper, and 2) other nodule mineral exporters, whose price will be strongly affected by the production of seabed minerals.

Copper. Five countries are quite heavily dependent upon their export earnings from copper, and another six countries derive from 2 to 6 percent of their export earnings from that metal (Table 4). The former in particular would tend to be wary of any change in the international economy which might threaten to reduce those earnings. Nonetheless, the first generation of ocean mining may have only a very small effect on these exporters. A 2-percent reduction in copper prices (as forecast by Adams) would go largely unnoticed given the 5- to 10-percent annual price swings typically observed in this market. Even the high estimate of 1980 seabed production would exceed 1974 copper-export earnings for only a single country, Uganda—a relatively minor producer. Over the longer term, however, rapid technological advances in ocean mining could create a more substantial threat to land-based copper producers.

Table 4
Countries Deriving At Least Two Percent of 1974 Export Earnings from Copper[1]
(Exports in millions of dollars)

	Copper Exports	Share of Total Exports
Zambia (1973)	$1,072.4	94.4%
Chile	1,898.0	76.5
Zaire	953.8	69.0
Peru	347.9	23.2
Philippines	396.7	14.7
South Africa	283.6	5.8
Yugoslavia	216.3	5.7
Uganda	16.9	5.4
Belgium–Luxemburg	1,042.6	3.7
Australia	303.8	2.8
Canada	661.6	2.0
Potential seabed output		
Low estimate	60.7	
High estimate	182.0	

[1] Includes both unrefined and refined copper (SIC Codes 682 and 283.11).
Source: *United Nations Yearbook of International Trade Statistics, 1975.*

Table 5
Countries Deriving At Least Two Percent of 1974 Total Export Earnings from Three Minerals Potentially Available for Ocean Mining
(Export earnings in millions of dollars)

	Export Earnings				Share of Total Export Earnings			
	Nickel	Cobalt	Manganese	All Exports	Nickel	Cobalt[2]	Manganese	Combined Share
Gabon	—	—	$33.7[1]	$177.8	—	—	19.0%[1]	19.0%
Dominican Republic	$93.1	—	—	636.8	14.6%	—	—	14.6
Zaire	—	$132.5[1]	2.0	1,381.5	—	9.6%[1]	0.3	9.9
Australia	115.8	—	16.0	10,787.3	1.1	—	3.1[1]	4.2
Norway	167.2	—	—	6,274.4	2.7	—	—	2.7
South Africa	40.7	—	84.5	4,906.1	0.8	—	1.7	2.5
New Hebrides	—	—	0.3	17.6	—	—	2.2	2.2
Seabed output:								
Low estimate	194.3	75.3	82.9					
High estimate	583.0	226.1	248.6					

[1] 1971 figures for Gabon and Zaire, and 1973 figure for Australia.
[2] Value of mine production of cobalt; export figure not available.
Source: *United Nations Yearbook of International Trade Statistics, 1975.*

Other minerals. Seven countries derive at least 2 percent of their export earnings from the other three nodule minerals, but only three of them obtain more than 5 percent of their foreign sales from these minerals (Table 5). They are Zaire (cobalt), Dominican Republic (nickel) and Gabon (manganese), which receive roughly 10, 15 and 20 percent, respectively, of their export earnings from such sources. Nonetheless, all of these countries are endangered by ocean mining, because even the low seabed estimates exceed most of their recent levels of production.

One government-owned firm in Zaire produces about 60 percent of the total world output of cobalt. Since the ocean could probably supply from one-third to all of the cobalt consumed in 1975 (Table 2), Zaire can plan on a noticeable loss in export earnings—perhaps approaching the full 10 percent of earnings the country now derives from cobalt. With Zaire's foreign-debt repayment problems, such a loss would not be easy to absorb.

The price of nickel could fall by roughly 12 percent, given an intermediate estimate of seabed production, so that all nickel exporters could experience some decline in export earnings. However, only the Dominican Republic obtains more than 3 percent of its foreign earnings from nickel (Table 5). Dominican export earnings are typically volatile because the country derives roughly half of its export earnings from sugar—a very mercurial commodity. The ocean-mining impact could be cushioned if the nickel price decline should occur during a sugar price boom—but of course the reverse would be true in the event of a slump in the sugar market.

The country most dependent upon the export of nodule minerals is Gabon, which earns about a fifth of its foreign exchange from mangenese. Like other nations, its potential losses would depend upon the efficiency of its mine operations. Should these mines be marginal, it could suffer an export-earnings decline of up to 20 percent (i.e., the share accounted for by manganese). Of course, any hardship should be cushioned somewhat by Gabon's oil holdings, which caused its export earnings to more than double between 1973 and 1974 alone.

Over the long run, the displacement of the land-based mining industry could be greater than indicated here, if the ocean-mining sector should lower its production costs substantially through economies of scale and rapid technological improvements. If that occurs, practically all the world's nickel could come from the ocean in four or five decades—and the same might be true elsewhere. On the other hand, ocean miners a century from now may be expressing serious concern over the threat of minerals from space.[17] But whatever happens over the long term, few countries are likely to suffer losses over the short term.

III. Third Group: Equitable Distribution of Benefits

We turn now to the third group of countries—those who neither intend to mine nor possess vulnerable land-based mining sectors, but simply want their share of the benefits of the "common heritage of mankind." Their position is easy to understand. The increasing acceptance of the "common heritage" notion makes them feel that they should benefit in some way from the exploitation of these minerals. However, an unregulated, untaxed ocean-mining industry would most likely permit the industrialized countries to capture the lion's share of the benefits. For that reason, this third group of countries desires some new institutional framework which will promote a more equitable distribution of benefits.

There is little doubt that the benefits of ocean mining will more than offset the losses. Any time society develops a more efficient method of production, it ends up with either more of that good or more of other goods, since resources now saved in the production of the first good can now be allocated to the production of others. Most technological changes probably involve a combination of these two effects.

In the case of ocean mining, extensive and lower-cost sources of industrially important minerals should ultimately lower the price to consumers of goods containing (or produced with) these minerals. This could happen because new mineral technology—that is, ocean mining—would tend to lower the cost of producing minerals, stimulate a rise in mineral output, and thereby lead to a fall in mineral prices. Cheaper minerals should stimulate mineral-using firms to expand their own output, thus causing a decline in the price of those goods. If all markets in this linkage are competitive, all cost savings would be passed on to consumers in the form of lower prices. Where markets are not competitive, monopolists and oligopolists would tend to transform some of the cost savings into higher profits.

The total benefits of ocean mining could be measured by the increase in consumer surplus plus the increase in factor rents attributable to ocean mining. However, the distribution of benefits would be heavily skewed toward the industrialized countries. Since only the large multinational corporations would have the size and expertise to undertake such activity, any rents generated would be captured by those firms and their factor suppliers. Developing countries could expect only a negligible (if any) share in the rents, since very few suppliers to (or stockholders in) the large ocean-mining firms would be likely to be residents of (non-oil-exporting) developing countries.

To the extent that people in developing countries consume goods containing or produced with ocean-based minerals, they will share in the increased consumer surplus generated by ocean mining. But since this share is proportional to consumption, and since consumption of most goods is positively related to the level of development, the developing countries would probably capture only a relatively small share of increased consumer surplus. For example, per capita consumption of copper in the United States and West Germany is more than 100 times per capita consumption in India (Table 6). Actually, the gap between the industrialized and developing countries is not quite so great as this would indicate, but a correction of the bias (if this were possible) would probably only reduce but not erase the gap (Table 6, footnote).

Table 6
Per Capita Copper and Nickel Consumption (1974)*
(Pounds)

	Copper	Nickel
West Germany	25.98	2.18
United States	20.76	2.02
Japan	17.71	2.39
Yugoslavia	11.34	0.15
Brazil	3.44	0.13
Albania	3.38	—
Mexico	2.51	—
India	0.18	—

*Consumption = production + imports − exports + declines in stocks. Thus consumption refers to use in production, regardless of whether the final products are used domestically or exported. To the extent that industrial countries are net exporters of manufacturers, their domestic consumption would be less than shown here, and to the extent that developing countries are net importers of manufactures, their domestic consumption would be greater than shown here. Thus the table would tend to overstate the gap between industrial and developing countries in terms of domestic mineral consumption in final products.

Sources: Population from *World Bank Atlas,* World Bank, 1976. Total Consumption from *Metal Statistics 1964–1974,* Frankfurt Am Main, 1975.

IV. A Solution?

In this paper, we have analyzed the positions of three groups of countries: 1) the industrialized countries—the potential ocean miners—which would receive the lion's share of the benefits under a free-access framework, 2) a small number of developing countries which stand to suffer temporary losses in export revenues, and 3) a very large number of countries which, although essentially unaffected by ocean mining, would still like to share in the benefits of what has come to be considered international property. It is not difficult to see that the interests of these groups are not in harmony. The first group stands to gain the most from a free-access, unregulated, first-come first-served framework. The second group would gain most from a total prohibition on ocean mining. The third group would gain most from a situation which allowed a competitive level of output, but which also taxed away all economic rent for redistribution according to some agreed-upon criterion.

The conflict between the first (industrialized) group and the third (uninvolved) group would be resolved if the first group satisfied itself with the consumer surplus and the third group captured the economic rent generated by the ocean-mining companies. Implementing such a solution could be difficult because of the problem of identifying economic rent for purposes of taxation. We need not get into a detailed discussion of this problem, but suffice it to say that the Single Revised Negotiating Text of the Law of the Sea Conference appears to provide a reasonable approach to a solution.

The conflict between both of these groups and the land-based mining group would not be reduced by this compromise, unless the latter were compensated in some way by the appropriated rents. This leads to a basic question: Can the advent of ocean mining make some people better off without making others worse off? To make that possible, the third group of countries would have to allow the general fund of appropriated rents to be reduced by an amount sufficient to compensate the land-based mining group, thus leaving less for themselves. Again, the fund of appropriated rents would have to be large enough to allow ample compensation for losses to the land-based mining group. While the total benefits of ocean mining (increased rents plus increased consumer surplus) would surely exceed the losses (the reduction in factor incomes in land-based mining), there is no assurance that the increase in rent alone would exceed the losses. Thus, even if the third group were willing, it might not be able to compensate the other group sufficiently out of the appropriated-rent fund.

Nonetheless, the total benefits would outweigh the total costs of ocean mining, since new and more efficient technologies could allow greater production with the same use of resources. Thus, it may not be either socially or economically useful to prevent the introduction of a new technology, simply because compensation of the losers is not administratively possible. In the distant past, the application of such a principle would have prevented the transition from the stone age to the age of metals, and thus would have prevented the development of those very land-based producers who are attempting to impede the progress of ocean mining today. In other words, prohibiting any technological innovation which does not allow full compensation of the losers would be a strong fetter on material progress. And if we believe that material progress is a desirable thing, then it may be better to have technological change without compensation than to have no technological change at all.

FOOTNOTES

1. This thought was first expressed in the Maltese Ambassador's 1967 speech to the United Nations, in which he declared that seabed resources were the "common heritage of mankind." In December, 1969, the UN passed Resolution 2574-D, better known as the "Moratorium Resolution," which declared that no claims to seabed ore deposits should be recognized and no seabed mining should take place until an international regime was established. A year later, the General Assembly passed a "Declaration of Principles," which stated that no party should acquire or exercise rights to the seabed that were incompatible with the yet-to-be decided international regime.

2. For the four major minerals contained in seabed nodules, the U.S. supplied the following proportions of its 1974 consumption requirements from domestic sources: copper, 81.8 percent; nickel, 7.3 percent; manganese, 2.3 percent; and cobalt, zero. **Mineral Facts and Problems,** 1975 (Washington, D.C.: U.S. Bureau of Mines, 1976).

3. Nodule value deflated by the IMF Index (not shown in Chart 1) exhibits a pattern almost identical to the one derived from the U.S. wholesale-price index.

4. Michael Gorham, "Ocean Mining in the Pacific Basin: Stimulus and Response," to be published in the **Proceedings of the Ninth Pacific Trade and Development Conference** in the summer of 1978.

5. Conrad Welling, "Ocean Mining System," **Mining Congress Journal,** (September 1976), p. 3.

6. Kennecott Copper Corporation, **Annual Report 1975,** p. 11. Kennecott's Nevada Mines experienced a 22-percent ore quality decline in a single year, from 0.78-percent copper in 1973 to 0.60-percent copper in 1974. **Op. cit.,** p. 10.

7. **Mineral Developments in the Eighties: Prospects and Problems,** Washington, D.C.: British-North American Committee and the National Planning Council, 1977; cited in testimony of Conrad G. Welling before the Mining Subcommittee of the House Committee on Interior and Insular Affairs (April 4, 1975), summary p. 2.

8. Welling, **op. cit.,** p. 2.

9. See Nina Cornell, "Manganese Nodule Mining and Economic Rent," **Natural Resources Journal** (Oct. 1974), p. 528 for the 9-percent estimate; and Danny M. Leipziger and James L. Mudge, **Seabed Mineral Resources and the Economic Interest of Developing Countries** (Cambridge, Mass.: Ballinger 1976), p. 159 for the 112-percent estimate.

10. Leipziger & Mudge, **op. cit.,** p. 161.

11. Leipziger and Mudge's work, which became known to this author after the present paper was in draft form, is a comprehensive treatment of the potential effect of ocean mining on the de-

veloping countries. There are no major differences between their results and those contained in this section.

12. The four groups include: Deepsea Ventures (U.S. Steel, Union Miniere of Belgium, and Tenneco holding the service contract), International Nickel Group (INCO of Canada, the German AMR group, and a Sumitomo-led Japanese group), Kennecott Copper Group (Kennecott, Rio Tinto Zinc of U.K., Consolidated Gold Fields, Noranda Mines and Mitsubishi), and Lockheed Group (Lockheed, Royal Dutch Shell and Standard Oil of Indiana).

13. One firm, Deepsea Ventures, apparently plans to process a portion of its nodules on the U.S. Gulf Coast and another portion in Belgium.

14. U.S. Steel, one of the major partners in Deepsea Ventures, may be trying to assure itself of a secure source of manganese, which is an essential ingredient of steel production.

15. F. Gerald Adams, "Applied Econometric Modeling of Non-Ferrous Metal Markets: The Case of Ocean Floor Nodules," in William A. Vogely (ed.), **Mineral Materials Modeling** (Washington, D.C.: Resources for the Future, 1975).

16. But since international consortia are involved, agreements could be made within each consortium to ship some of the processed metal to Japan or Europe, which would mean displacing Japanese or European as well as U.S. imports.

17. A recent article quite seriously discussed the technical feasibility of extracting nickel and other minerals from asteroids. T.B. McCord and M.J. Gaffey, "Mining Outer Space," **Technology Review** (June 1977), pp. 50–59.